CO_2P_3S Installation Guide and User Manual Version 1.0

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Abstract

This document is an installation guide and user manual for Version 1.0 of the CO_2P_3S parallel programming system. CO_2P_3S is a programming system for designing, coding, and executing parallel programs that execute in a shared memory environment. CO_2P_3S generates framework code from a design pattern description of the structure of a program. The framework code contains all of the necessary communication and synchronization for the selected program structure. Application code is inserted by implementing sequential hook methods that are called by the larger framework structure.

1 Introduction

CO_2P_3S (Correct Object–Oriented Pattern–based Parallel Programming System, pronounced "cops") combines design patterns and object–oriented frameworks into a process for writing high–performance object–oriented programs that execute on multiple processors. At the highest level of application development, you specify the parallel structure of your program using a set of supported *design pattern templates*. Much like the patterns they are based upon, pattern templates represent a family of solutions to a design problem. You specialize the pattern template to select the most appropriate member of this family by specifying values for *design pattern template parameters*. Once the best pattern structure is selected, the pattern template is used to generate object–oriented framework code implementing the specific structure that you've selected. CO_2P_3S currently generates multithreaded Java code targeted at shared memory multiprocessors. This framework code encapsulates all of the communication and synchronization code needed for the selected structure, and is hidden from you to reduce the possibility of errors. To complete a program, you need only implement sequential hook methods that are invoked from the generated structure. Lower layers gradually expose the generated code using high–level abstractions, and then the implementation of these abstractions. These layers provide performance tuning opportunities and flexibility in a controlled manner.

This document serves as an installation guide and user manual for the CO_2P_3S parallel programming system. Section 2 describes the steps in the installation process. This section describes the general process; this release of CO_2P_3S was assembled with some of these steps already completed to minimize your effort. Section 3 describes the execution environment and general programming model of CO_2P_3S. Section 4 shows the features of the user interface in detail. Note that this section does not describe the pattern templates in detail. Documentation for the templates

is available through the interface. Section 5 gives a glimpse of the future, showing some of the research currently underway that we hope to incorporate into future releases of CO_2P_3S.

2 Installing CO_2P_3S

2.1 Operating System

We have successfully run CO_2P_3S using native-threaded Java virtual machines (VMs) on the following operating systems:

- Linux
- Solaris
- SGI Irix

Since CO_2P_3S is a Java tool generating Java code, it may run on other platforms. However, we did not develop the tool with portability in mind, so we cannot guarantee that either the tool or the generated framework code will run correctly on other platforms. You may experience problems with the CO_2P_3S user interface. Differences in thread scheduling policies on different operating systems may cause problems in the generated frameworks. If you successfully use CO_2P_3S on a different operating system, please let us know and we will add it to the above list.

2.2 Other System Requirements

You will need the following hardware configuration and software installed on your system for CO_2P_3S to work properly:

- A Java distribution, Version 1.2 or higher. This distribution must include both a compiler and a run–time environment. The run–time environment must support native threads to take advantage of multiple processors.
- A Perl distribution, Version 5 or higher. It must be possible to start the executable using the command:

  /usr/bin/perl

  This can be either the executable program or a link to the executable.
- Any version of GNU make. This is required to compile your CO_2P_3S distribution.
- A computer with an active network connection. CO_2P_3S uses XML documents to store relevant program and tool configuration information, and the document descriptions are accessed via the World Wide Web. It is possible to work around this requirement; see Section 4.7 for details.

- If you want parallel speedups, you will need a shared memory multiprocessor computer system. CO_2P_3S will work on uniprocessor machines, but you will not likely experience any performance improvements. In fact, you will most likely experience performance degradation. However, when testing for the correctness of a program, such a system may still be useful.

2.3 CO_2P_3S Installation Process

To compile and install CO_2P_3S on your computer, you will need to do the following:

1. Obtain a copy of the source code distribution. This comes as either a gzipped tar file or a zip file. This is available through the World Wide Web at:

   `http://www.cs.ualberta.ca/~systems/cops/index.html`

   through the `Downloads` link on the left–hand frame.

2. Select a directory for your CO_2P_3S installation, which we will refer to as `COPSDIR` for the rest of this document. Extract the contents of the distribution. The CO_2P_3S distribution will unarchive into a subdirectory "`copsProj`". For the gzipped tar file, use the command (where "%" is your shell prompt, and replacing `copsDistribution.tar.gz` with the name of the distribution file):

   ```
   % tar xfz copsDistribution.tar.gz
   ```

   or

   ```
   % zcat copsDistribution.tar.gz | tar x
   ```

   For a zip file, use the command

   ```
   % unzip copsDistribution.zip
   ```

3. Add the following directories and JAR files to your `CLASSPATH` variable, using the correct means for your operating system or shell:

   - `COPSDIR/copsProj`
   - `COPSDIR/copsProj/libs/jdom.jar`
   - `COPSDIR/copsProj/libs/xalan.jar`
   - `COPSDIR/copsProj/libs/xerces.jar`
   - `COPSDIR/copsProj/libs/jini-core.jar`
   - `COPSDIR/copsProj/libs/jini-ext.jar`

   (The last two items will be used by future releases of CO_2P_3S, which will support distributed memory programs.) This step must be done before you compile or run CO_2P_3S.

4. Add the following directory to your `PATH` variable:

- `COPSDIR/binUtil`

This step must be done before you compile or run CO_2P_3S.

5. The current release has already been compiled, so you can skip this step. However, you still need to complete all of the earlier steps. If you have a source–only distribution, you will need to build CO_2P_3S. Change to the directory `COPSDIR/copsProj`. Build the distribution using the command (where "`%`" is your shell prompt):

```
% make
```

2.4 Configuring CO_2P_3S

After compiling CO_2P_3S, you must configure it before you can execute it. CO_2P_3S configuration consists of two stages. The first stage is setting the properties for the user interface. The second stage is adding pattern templates to the user interface. Since the second stage requires you to run the CO_2P_3S user interface, this process is also described in this section.

This release of CO_2P_3S was assembled to minimize the amount of work you need to do before using the system. As a result, some of the steps below are not required. However, this information will be useful for future releases.

2.4.1 CO_2P_3S Properties

First, copy the file `COPSDIR/copsProj/copsrc.xml` to `$HOME/.copsrc.xml` (note the extra period). `$HOME` is your home directory as defined by the Java system property `user.home`. If you are unsure about the value of this property, you can get it by printing the result of the Java method call:

```
System.getProperties().getProperty("user.home")
```

In a UNIX environment, this should correspond to your normal home directory.

Now, edit the file `$HOME/.copsrc.xml`. The default file is shown in Figure 1. This file contains configuration properties used by the CO_2P_3S graphical user interface. Some of these properties must be filled in before CO_2P_3S can be run. Some can be reset or must be set through the user interface.

The first part of the XML file consists of header and definition information. You should not find it necessary to change any part of the first 9 lines (with one possible exception). Lines 1 is header information regarding the XML file. Lines 2 and 3 are a comment indicating the purpose and location for this file. Line 4 and 5 indicate where the DTD (Document Type Definition) file for this document can be found. The DTD file indicates the format of the XML file, including all legal tags. Since this file is referenced through a URL, your machine must have an active network connection for CO_2P_3S to work properly. See Section 4.7 for a workaround if you plan to use CO_2P_3S on a machine that cannot access this URL. Lines 7 and 8 define a name space for the XML document. CO_2P_3S will work properly if you cannot access this URL.

The region of interest in the `.copsrc.xml` file starts at line 10 and ends at line 39. The format of the configuration fields is that of standard XML. Each field starts with the XML tag

```xml
<?xml version=“1.0”?>
<!- - This is a sample RC file for the CO2P3S program. The location
for this file on the user’s system is $HOME/.copsrc.xml - ->
<!DOCTYPE CopsCfg:copsCfg SYSTEM
      “http://www.cs.ualberta.ca/∼systems/DTD/1.0/CopsCfg.dtd”>

<CopsCfg:copsCfg
      xmlns:CopsCfg=“http://www/cs.ualberta.ca/∼systems/cops/cfg/”>

      <CopsCfg:copsInstallationDirectory>
            installation path of COPS
      </CopsCfg:copsInstallationDirectory>

      <CopsCfg:userProgramDirectory>
            path to user programs
      </CopsCfg:userProgramDirectory>

      <CopsCfg:defaultEditor>
            name of default Java code editor
      </CopsCfg:defaultEditor>

      <CopsCfg:htmlBrowser>
            name of HTML browser
      </CopsCfg:htmlBrowser>

      <CopsCfg:patterns>
            <CopsCfg:patternName>Mesh</CopsCfg:patternName>
            <CopsCfg:patternName>Distributor</CopsCfg:patternName>
            <CopsCfg:patternName>Phases</CopsCfg:patternName>
      </CopsCfg:patterns>

      <CopsCfg:jiniPolicyDirectory>
            install path of COPS/Distributed/JINI/policy/policy.all
      </CopsCfg:jiniPolicyDirectory>

      <CopsCfg:jiniLUSAddress>
            URL for lookup service
      </CopsCfg:jiniLUSAddress>
</CopsCfg:copsCfg>
```

Figure 1: The default XML file that comes with a CO_2P_3S distribution.

<CopsCfg:*fieldName*>

where *fieldName* is the name of the configuration field. The field ends with the tag

</CopsCfg:*fieldName*>

where *fieldName* must match the starting tag. The value of the field is contained between these two tags. Tags can appear inside of other tags, but they must be properly nested.

The current CO_2P_3S configuration has the following fields:

copsInstallationDirectory This is the path to the CO_2P_3S installation. This field has to be filled in manually, before CO_2P_3S is run the first time. The correct value for this field is `COPSDIR/copsProj`. From this point onward, `COPSINSTALL` refers to this directory.

userProgramDirectory This is the full path of default directory for your CO_2P_3S programs. If no value is entered or the supplied directory does not exist, your home directory (as defined earlier in this section) is used. This can be entered either here or through the user interface. However, because of interface limitations (described in Section 4.7), it should be filled in before you open or create a program in CO_2P_3S for the first time.

defaultEditor This is the name of your favourite text editor. This editor is used to edit extra program files that you wish to incorporate into a CO_2P_3S program. This field can be entered now or entered later using the CO_2P_3S interface. Note that the selected editor must execute in its own window, as CO_2P_3S will not do this for you. For editors such as `emacs` and `gvim`, this is not a problem. On the other hand, `vi` does not start its own window. On X11 systems, this can be remedied by specifying

```
xterm -e vi
```

as the value of this attribute. You can replace `vi` with other console–based editors.

htmlBrowser This is the name of your favourite HTML browser. This browser will be used to display HTML documentation for the design pattern templates in CO_2P_3S. This field can be entered now or entered later using the CO_2P_3S interface. As with the editor, this browser must execute in its own window, so browsers such as `lynx` must be started the same way that the `vi` editor is above. However, most of the documentation pages also include graphics, so a graphical browser is best.

patterns This field contains a list of the current pattern templates that have been loaded into the CO_2P_3S interface. You should not change this field manually. It will be updated as you add and remove templates in the interface, as described in Section 2.4.3. This field already includes entries for the three pattern templates provided with this distribution of CO_2P_3S.

jiniPolicyDirectory This field is for future releases of CO_2P_3S that will include distributed pattern templates. This field is not used in this distribution, but the field must still appear in the configuration file. Simply use the current value.

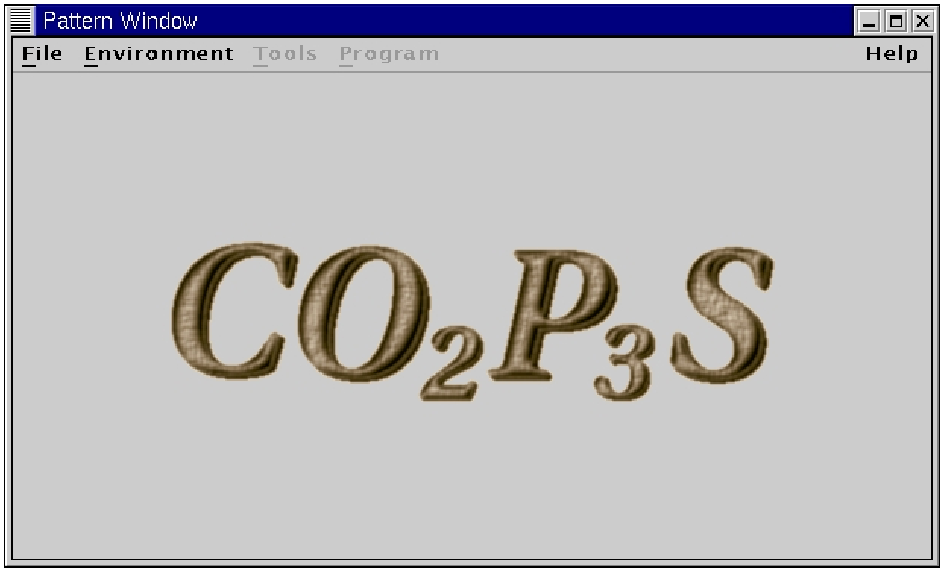


Figure 2: The initial screen of CO_2P_3S.

jiniLUSAddress This field is for future releases of CO_2P_3S that will include distributed pattern templates. Again, this field is not used in this distribution, but the field must still appear in the configuration file. Simply use the current value.

Line 39 ends the configuration file.

2.4.2 Running CO_2P_3S

To run CO_2P_3S, use the script supplied with the distribution. This script can be found at

```
COPSINSTALL/runCops
```

Right now, this must be executed while your current directory is `COPSINSTALL` for the images in the interface to be displayed correctly. When CO_2P_3S is run, a log file `cops.log` is created in the current directory. This file logs events and errors in the user interface. If you experience problems, you can view the log by selecting `View Log` from the `File` menu.

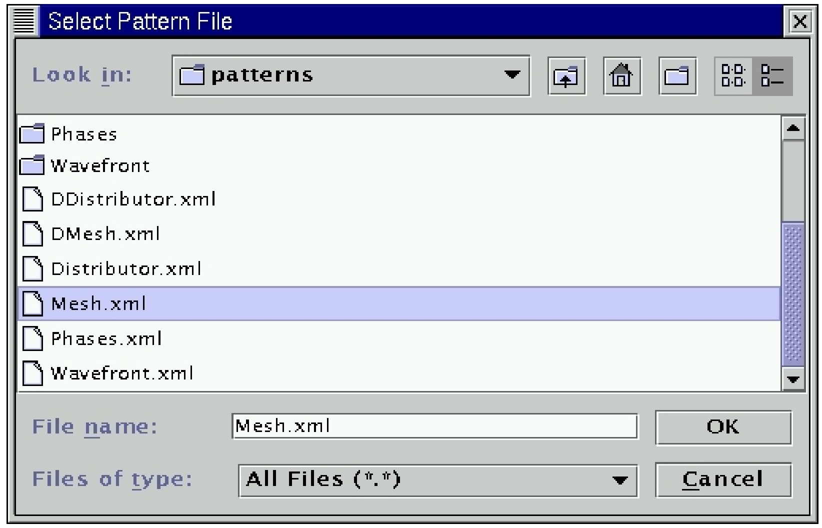
The initial screen for CO_2P_3S is shown in Figure 2. For the remainder of this section, the menus at the top of the window are the points of interest.

2.4.3 Adding Pattern Templates to CO_2P_3S

When you first start CO_2P_3S, it will have three pattern templates already installed: the Two–Dimensional Mesh, the Phases, and the Distributor. These three pattern template will appear when you create a new program or open an existing one. You can use these templates in your programs. However, CO_2P_3S is an extensible system that allows you to add new pattern templates as they are developed. Later distributions will include tools to help you create your own pattern templates, and we hope to create a repository for you to exchange your templates with other users.

The process of adding a new pattern template is best done from the initial CO_2P_3S screen (Figure 2), as follows:

(a) The `Environment` menu.



(b) The pattern file selection dialog.

Figure 3: User interface elements for adding pattern templates in CO_2P_3S.

1. Select the `Environment` menu from the menu bar on the top of the interface. Then select `Import Pattern`, shown in Figure 3(a).
2. After you select `Import Pattern`, the dialog in Figure 3(b) will appear. You use this dialog to select a pattern template to import. By default, this dialog looks for pattern templates in the directory `COPSINSTALL/patterns`, which is where the templates bundled with your CO_2P_3S distribution can be found. If you have downloaded other patterns, navigate to the directory where you have installed them.
3. Once you have navigated to the appropriate directory, select the XML file for the pattern template you wish to add. Select it and click `OK`, and wait for the template to load. This process can take some time, as the contents of the XML file are used to generate Java source code which is then compiled.
4. You can repeat the last two steps for all pattern templates you wish to add.
5. As the interface instructs you, quit CO_2P_3S (by selecting `Quit` from the `File` menu). The new pattern templates will be available the next time you start CO_2P_3S. (This is why we recommend you add new templates from the initial screen, so you don't interrupt work on a current program.)

2.4.4 Removing Pattern Templates from CO_2P_3S

If you decide that a pattern template is no longer useful, you can remove it from CO_2P_3S. As with adding a template, this can be done from the initial CO_2P_3S screen. However, if you do so, you will not be able to modify any programs that use that pattern template.

Figure 4: Removing a pattern template from CO_2P_3S.

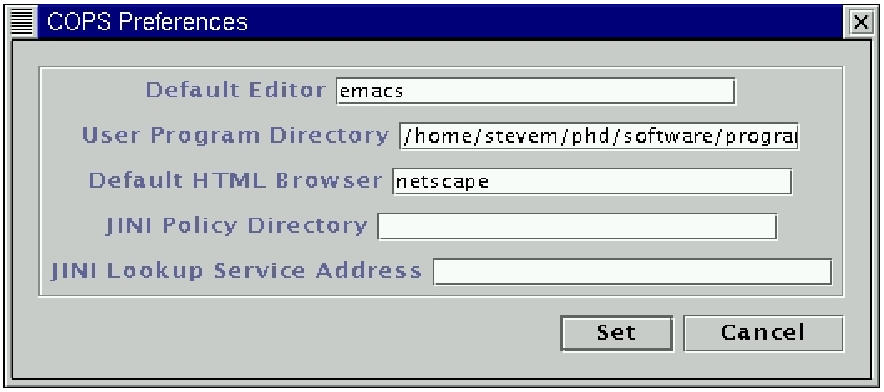


Figure 5: The Preferences dialog.

To remove a pattern template, select the `Environment` menu item from the menu bar at the top of the interface. From this menu, select `Remove Pattern` (Figure 3(a)). This is a cascaded menu item, where the items that appear are a list of the currently imported pattern templates. Select the pattern template that you wish to remove, as shown in Figure 4. After you confirm your selection, the pattern template will be removed from CO_2P_3S. It can be added back into CO_2P_3S using the process in Section 2.4.3.

2.5 Setting Preferences with the Graphical User Interface

From the `Environment` menu (Figure 3(a)), you can set your CO_2P_3S preferences at any time by selecting `Preferences`. When you select this item, the dialog in Figure 5 appears. This dialog allows you to set the userProgramDirectory, defaultEditor, htmlBrowser, jiniPolicyDirectory, and jiniLUSAddress properties described in Section 2.4.1. The remaining properties cannot be set through this dialog.

3 About CO_2P_3S

This section describes some of the more general details of the CO_2P_3S parallel programming system. This includes information on the execution environment for your programs and the programming model supported by the tool.

3.1 Execution Environment

CO_2P_3S generates multithreaded Java code for the supported parallel design pattern templates. This code can be run on a uniprocessor or shared memory multiprocessor. On a multiprocessor system, you can used native threads, which allows the Java Virtual Machine to map the threads to different processors. This will hopefully result in performance improvements, by using different processors to execute different parts of your program in parallel.

CO_2P_3S assumes that there is an active network connection. This connection is used to verify the validity of some of the XML files contained within the CO_2P_3S system. Section 4.7 contains instructions for removing this dependency if you need to.

CO_2P_3S has no special requirements regarding file systems. Applications that use disk will need to make sure files are available to all threads that need them. On most shared memory machines, this should not be an issue.

3.2 Programming Model

The programming model for CO_2P_3S consists of three layers of user–accessible abstraction. Each layer provides distinct abstractions supporting different phases of program development. In addition, each layer gradually exposes more implementation details of the object–oriented framework code generated by CO_2P_3S, providing *openness* (which, in this sense, means that you can access low–level structures and run–time code to improve the performance of your application). More information on programming in CO_2P_3S can be found in our papers available through the `Publications` link at

`http://www.cs.ualberta.ca/~systems/cops/index.html`

The layers of CO_2P_3S are listed below. The current distribution only supports the topmost layer. The layers are:

Patterns Layer At this layer, you express the structure of your program by selecting the appropriate *parallel design pattern templates*. A design pattern template is a design construct that represents a family of related design pattern implementations. Each implementation has the same basic structure, but each is a slight structural variation that makes the pattern more applicable to your specific problem. To select the member of the family that best suits your problem, you provide values for *pattern template parameters* associated with each template.

After you have provided appropriate values for the pattern template parameters, you use the fully–specified template to create an object–oriented framework that implements the selected pattern structure. An object–oriented framework is a set of (usually) abstract classes that provide a design and partial implementation of the application–independent part of a specific kind of application, such as a graphical user interface. In our case, the application domain is the implementation of a parallel structural pattern. The structural part of the framework calls a set of *hook methods* at execution points where application–specific operations are required. You complete a program by providing implementations of these hook methods by subclassing the framework classes and overriding the required methods.

For our parallel frameworks, the structural code includes all of the error–prone communication and synchronization code required by a pattern implementation. The hook methods

are sequential code. They do not require any parallel code for the framework to operate correctly. In many programs, the hook method code for a generated framework can be taken directly from an existing sequential program, possibly using the Adapter design pattern [1].

Documentation on the pattern template parameters and the generated framework code is provided with each template and is not part of this document.

To reduce the possibility of programmer error, the structural framework code is encapsulated away from you at this layer of development. Other errors are prevented through the user interface, which is illustrated in Section 4.

Intermediate Code Layer This layer provides a high–level explicitly parallel programming language based on a superset of an existing language, such as Java or C++. It provides high–level abstractions for expressing parallelism and synchronization.

At this layer, the structural framework code generated at the Patterns Layer is made available, implemented in the high–level language. You can optimize the code or implement a pattern variation that is not supported by the template parameters. Alternately, you can skip the Patterns Layer and write programs directly in this language.

Native Code Layer This layer provides a base object–oriented programming language together with any libraries used to implement the abstractions in higher layers. The libraries can be optimized for your particular execution environment.

4 The CO_2P_3S Graphical User Interface

4.1 Program Organization

A CO_2P_3S program is a directory with the following subdirectories:

src This subdirectory contains the complete source code for a CO_2P_3S program. This code includes both the generated source code and additional source file you add to your program (Section 4.4.3). You should use the CO_2P_3S user interface to work on all of these source files. Otherwise, any changes you make may be overwritten during source code generation.

classes This subdirectory contains the Java bytecode files for the program.

cops_patterns This subdirectory contains saved information on the pattern templates in your CO_2P_3S program. You should not change any of the contents of this directory.

cops_html This subdirectory contains HTML files for the classes with hook methods for a given framework. Again, the contents of this subdirectory should not be modified.

cops_methods This subdirectory contains the bodies of the application–specific hook methods that you have implemented. The contents should not be altered manually.

Other directories are also included in a CO_2P_3S program, and you can create others to manage additional data for your application. It is important that you not modify the contents of any of the above directories by hand. The user interface provides safe access to the files that you can modify.

Figure 6: The `File` menu.

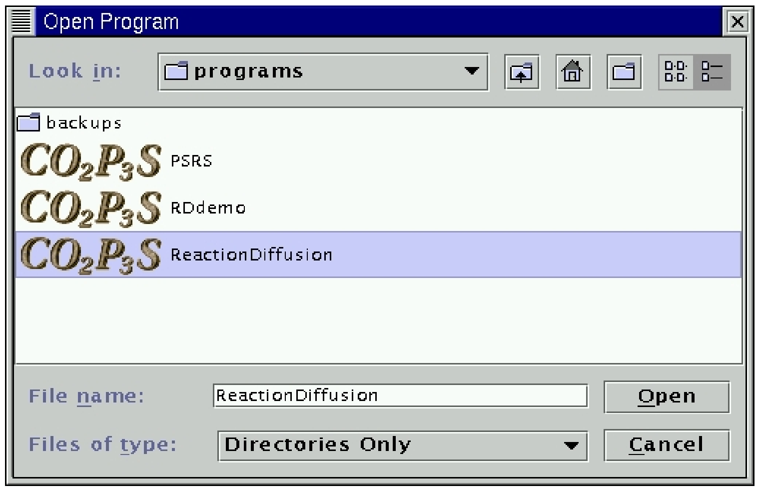


Figure 7: The dialog for opening a CO_2P_3S program.

4.2 Opening or Creating a CO_2P_3S Program

The first step in working with CO_2P_3S is to open an existing program or create a new one. These operations are available through the `File` menu (Figure 6). The dialog for opening a program is given in Figure 7.

This dialog starts looking for CO_2P_3S programs in the directory indicated by the userProgramDirectory attribute in your preferences. This is the standard file chooser in Java, and can be used to navigate your files. The items with the CO_2P_3S logo on the left are directories with a subdirectory structure matching that described in Section 4.1. You can select one of these directories and select `Open` to work on that program.

Creating a new program is almost identical. A similar file chooser appears, again starting in the directory indicated in your preferences. You navigate to where you would like your program to be kept and enter in the name of the program. The directory for the program, including all of its subdirectories, is created. The empty program is opened and you can begin work on it.

4.3 Saving a CO_2P_3S Program

Of course, you will want to save the state of your CO_2P_3S programs as you work on them. This is done by selecting `Save` from the `File` menu. It is important to note that this only saves the

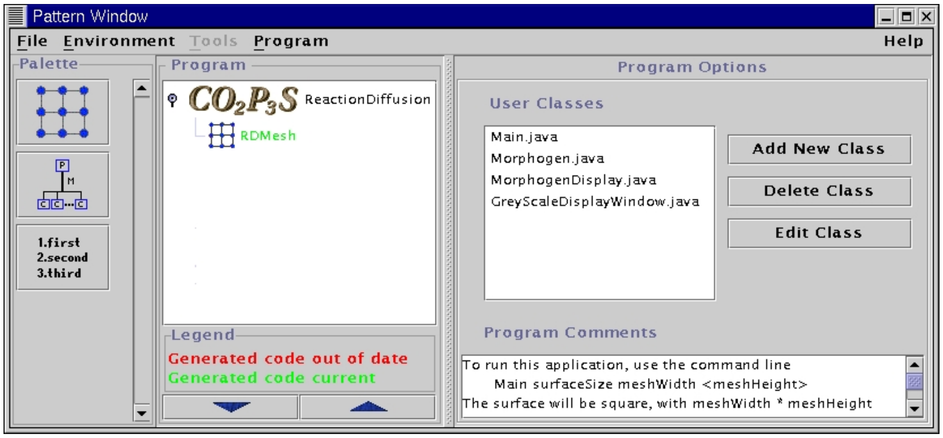


Figure 8: An open CO_2P_3S program.

configuration information of a program, such as the current set of patterns and their values.

Unfortunately, many other changes to a CO_2P_3S program take effect immediately and cannot be undone by simply not saving the program. You should save your program after making structural changes to it, or you will find that the program state and the state displayed in the user interface may not agree when the program is opened later.

For example, if you change a pattern template parameter and regenerate the framework code, you cannot undo the changes by not saving the program. The next time you load the program, the code will be that for the modified parameter value while the interface displays the old value. Similarly, application code is saved as you change it, and will persist regardless of whether or not you save your program.

4.4 Working With a CO_2P_3S Program

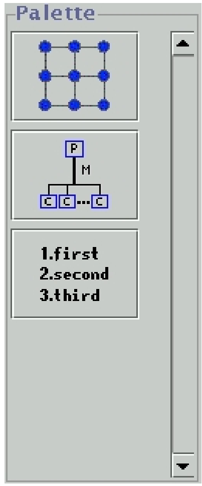
To make the presentation of this section more concrete, we have opened the reaction–diffusion example programs provided with your CO_2P_3S distribution. Initially it will appear as shown in Figure 8. This section describes each part of the user interface as well as the compilation and execution facilities.

4.4.1 Pattern Palette

The first part of the interface we will examine is the Pattern Palette on the left of Figure 8. A closeup is shown in Figure 9(a).

The Pattern Palette allows you to select from the set of support design pattern templates, represented as buttons on the palette. In Figure 9(a), the templates (from top to bottom) are the Two–Dimensional Mesh, the Distributor, and the Phases. You can always get the name of the template by placing the cursor in the button and waiting for the tool tip.

Left–clicking on a button includes the pattern template into the current program. The pattern will appear in the Program Pane (Section 4.4.2) and in the Pattern Pane (Section 4.4.4). Right–clicking on a button brings up the background menu, shown in Figure 9(b). You can add the pattern to the program (`Insert Pattern`) or view the pattern template documentation (`Pattern`



(a) The Pattern Palette.

(b) The background menu for the pattern templates.

Figure 9: The Pattern Palette and background menu.

`Help`) using the HTML browser specified in your preferences.

4.4.2 Program Pane

The Program Pane is the middle section of Figure 8. An expanded picture is in Figure 10. This pane shows the set of pattern templates that are part of the current program.

The topmost item, with the CO_2P_3S logo followed by the program name, represents the entire program. Beneath it is a list of the pattern templates that are used in the current program. Each item in the list is a small graphical representation of the template followed by its name. The name of a pattern template is based on one of its parameter values, which allows you to distinguish between different instances of the same template. In our example, we are using an instance of the Mesh template with the name `RDMesh`.

The Program Pane also indicates the status of each pattern template using colours for the template name. The colours are:

Red This colour indicates that the framework code is out of date. This either means that you have not generated code for this template, or you have changed a pattern template parameter value and the generated code may not be consistent with the current parameters. You can generate code from the Pattern Pane (Section 4.4.4) or the Compile dialog (Section 4.4.5).

Green The framework code is consistent with the current parameter values.

The meaning of these colours is indicated by the legend that appears at the bottom of the Program Pane.

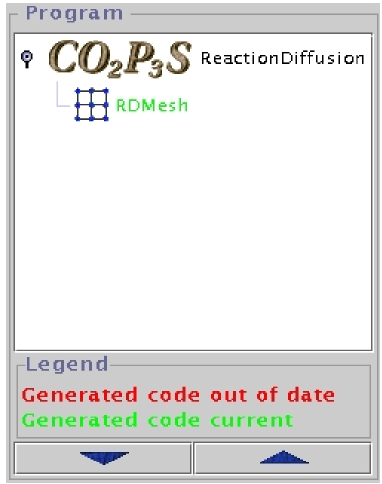


Figure 10: The Program Pane.

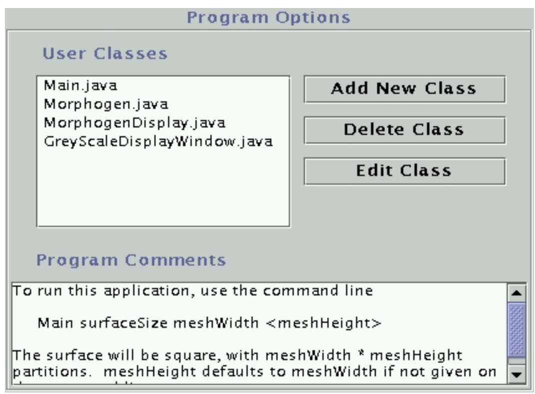


Figure 11: The Program Options Pane.

4.4.3 Program Options Pane

When the topmost item in the Program Pane is selected, the Program Options Pane appears on the right side of the interface. This is the case in Figure 8, shown again in Figure 11.

The Program Options Pane allows you to provide information for the entire program. This consists of two components: user classes and program comments.

User classes, the top part of the Program Options Pane, let you create additional classes for your application. In all CO_2P_3S programs, you will need to supply a mainline class, but other classes (perhaps from sequential versions of your program) can also be included. In addition to the mainline, the reaction–diffusion example uses three additional classes. You can add new classes using the `Add New Class` button, where you will be prompted for the name of the new class. This should be entered without the `.java` suffix. You can select a user class and delete it from the program. You can also select a class and edit it using the editor in your preferences.

The bottom part of the Program Options Pane provides space for program comments. In Figure 11, this space is used to provide information on the command line arguments for the program.

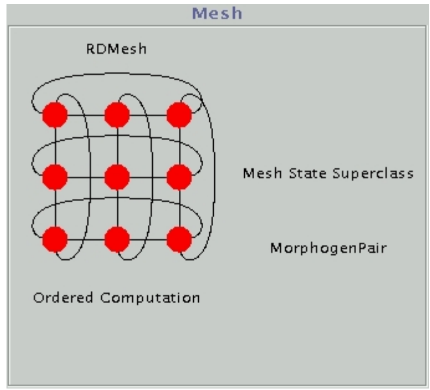


Figure 12: The Pattern Pane, showing an instance of the Mesh pattern template.

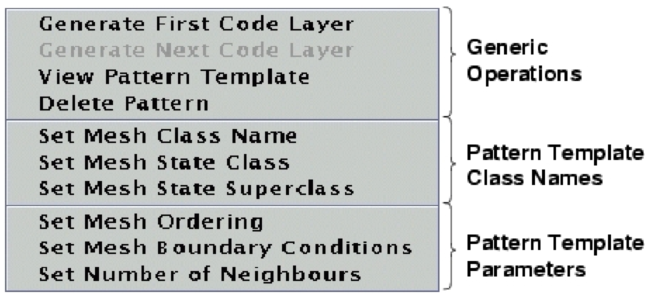


Figure 13: The background menu in the Pattern Pane.

4.4.4 Pattern Pane

If you select one of the pattern template instances in the Program Pane, the Program Options Pane is replaced by the Pattern Pane for the selected instance of a pattern template. The Pattern Pane on an instance of the Mesh is shown in Figure 12.

The Pattern Pane shows details on a specific instance of a pattern template, such as the current values of its parameters. This information is depicted using a combination of text and graphics. In Figure 12, we can see several class names (`RDMesh` and `MorphogenPair`) as well as other parameter values (a four–point mesh, a fully–toroidal topology, and an ordered computation).

The Pattern Pane is also used to work with the pattern template and generated framework code. The pane allows you to change parameter values to refine the template, generate code from a fully–specified template, and insert hook method bodies to complete the implementation of a program. Some aspects of this functionality are common to all pattern templates and are discussed here. Other aspects are necessarily specific to a particular pattern template and are covered in more detail in the template documentation.

The pattern template is refined using a background menu in the Pattern Pane, obtained by right–clicking anywhere in the pane. The menu for the Mesh pattern template is shown in Figure 13. The operations in this menu can be broken down into three categories: generic operations that apply to all pattern templates, pattern template class names, and pattern template parameters. The latter two categories are specific to each pattern template and are discussed in the template documentation.

The first menu item in the generic operations, `Generate First Layer Code`, generates

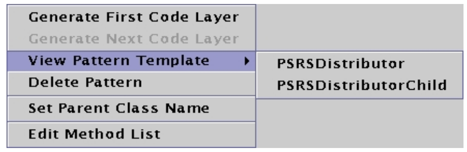


Figure 14: The background menu for the Pattern Pane with multiple viewable templates.

Patterns Layer code from the pattern template using the current template parameter values. If code is successfully generated, the label for the template in the Program Pane will turn green. The `Generate Next Code Layer` item is disabled since this release only supports the Patterns Layer. It will be enabled in the future when there is more support for the two lower layers in the CO_2P_3S programming model.

The last menu item in the generic operations, `Delete Pattern`, deletes the current pattern and associated files from your program. Note that this deletion takes place immediately and cannot be undone later.

The middle menu item is `View Pattern Template`. This item allows you to add hook method bodies to generated framework code, and so is only available when the generated framework code is up–to–date. Selecting this item brings up a Viewing Template window, shown in Figure 15, that allows you to view and edit hook method bodies for the current framework. If there are multiple classes in a framework that have hook methods, this item becomes a cascaded menu item (indicated by an arrow to the right) and you can select the class you wish to edit (Figure 14). Either a new viewer for the class will appear, or an existing viewer for the selected class will be brought to the foreground.

The Viewing Template window is a modified HTML viewer where the links represent places where you can add or edit code. The code in the viewer is generated with the framework code for a pattern template, and is run through a code beautifier before being displayed. If you select a link, a Code Editor dialog appears, shown in Figure 16.

The Code Editor dialog allows you to modify the code for particular method in the viewer. This editor is not the one in your preferences, but rather is a dialog that was created specifically to prevent errors involving hook method signatures. The combination of the Viewing Template and Code Editor dialogs do not allow you an opportunity to edit the signatures of the hook methods. Further, the code is generated for you, saving you from having to enter these signatures. This is important because the remaining framework code relies on the methods in the class in the viewer having specific signatures for the code to operate correctly. This tool support ensures that these signatures cannot be changed and prevents some potential compile and logic errors. As an example of the latter error, consider the first two arguments to the constructor at the top of the code in Figure 15. These two arguments represent the location in a two–dimensional data structure for the element being created. If you had to write this signature or were able to change it, you could accidently reverse the two parameters. This error cannot be caught by the compiler since the parameter types are correct, which is all the compiler checks. However, the framework code that uses this constructor is assuming the order in the figure. Reversing the parameters causes the data to be transposed, which may cause errors later.

In the Code Editor dialog, you can also restore the default implementation of a hook method by clicking the `Restore Default` button. This replaces the current value of the hook method with

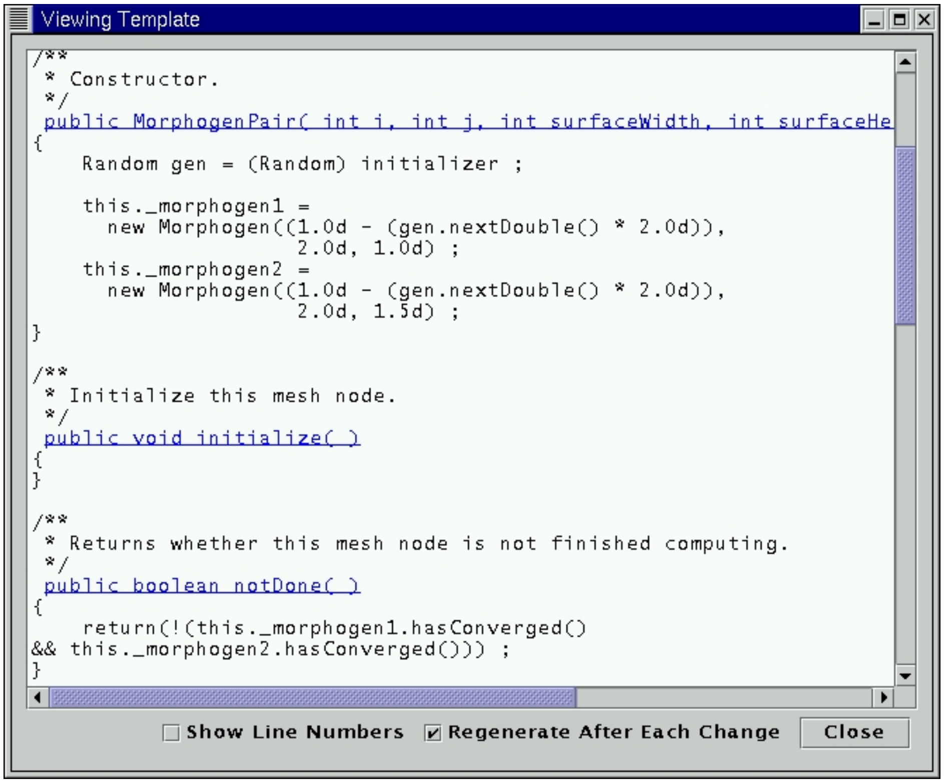


Figure 15: The Viewing Template for editing application code in the framework generated for a pattern template.

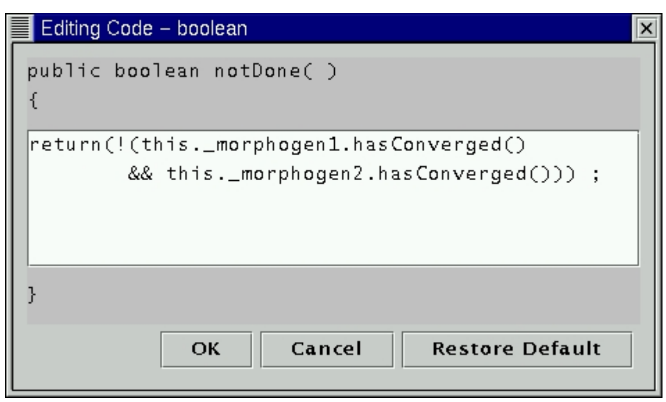


Figure 16: The Code Editor dialog.

Figure 17: The Program menu.

the default as generated with the framework code. An important note is that, because of a problem with the current implementation, the code editor does not display any code for those methods with the default implementation. The correct method body is still in the actual source code, but is not displayed in the code editor. However, if you click `OK` on a code editor with an empty body, you will overwrite the default with a blank body. This will cause compilation errors later. To preserve the default, either cancel the change or restore the default.

After restoring the default or accepting a new method body, CO_2P_3S will normally regenerate source code for the framework to incorporate this new code, and display the updated code in the viewer. This regeneration can incur an unwelcome time delay. You can disable this regeneration by unchecking the `Regenerate After Each Change` checkbox at the bottom of the Viewing Template. This speeds up the code editing process. Changes to method bodies are no longer reflected in the viewer. However, the changes are still visible in the code editors. If any methods are changed, the background of the viewer will turn grey and a label will appear at the bottom of the dialog, making it is clear that the displayed code is out–of–date. An out–of–date viewer can be refreshed by rechecking the `Regenerate After Each Change`. Closing an out–of–date viewer (by clicking the `Close` button) will force a code regeneration, so current code will appear if the template is brought up again later.

Checking the `Show Line Numbers` checkbox at the bottom of the Viewing Template window cause line numbers for the source code to appear on the left side of the viewer. This feature allows you to easily find compile errors in the code in this window.

Note that if you regenerate the framework code, using either the `Generate First Layer Code` menu item or the option in the Compile dialog (Section 4.4.5), all Viewing Template and associated Code Editor dialogs for that pattern template are closed. It is possible for you to change some of the class names in the generated code, which may mean that the class displayed in the viewer may no longer be part of your program. The best way to ensure that this window always displays a relevant class is to close it and have you open another viewer, which will always be on a class that is part of the current framework.

4.4.5 Compile Dialog

Once you have entered all of your application code, you need to compile the code. This is done by selecting the `Compile` item from the `Program` menu, shown in Figure 17.

The Compile dialog, shown in Figure 18, will appear. Selecting `Compile` will compile you program with the arguments supplied in the dialog. `Clean` will remove all of your `.class` files. `Abort` stops any currently executing compilation.

The `Regenerate All Layer One Source` button performs two functions. First, it removes all source files (except the user classes entered using the Program Options Pane (Section 4.4.3)), class files, and HTML files for the program. Second, it regenerates source code and HTML files for all patterns in the program using the current values of the pattern template param-

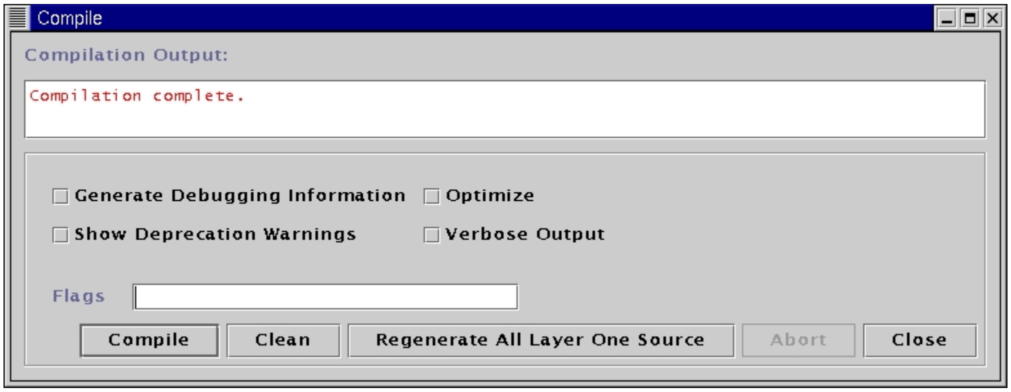


Figure 18: The Compile dialog.

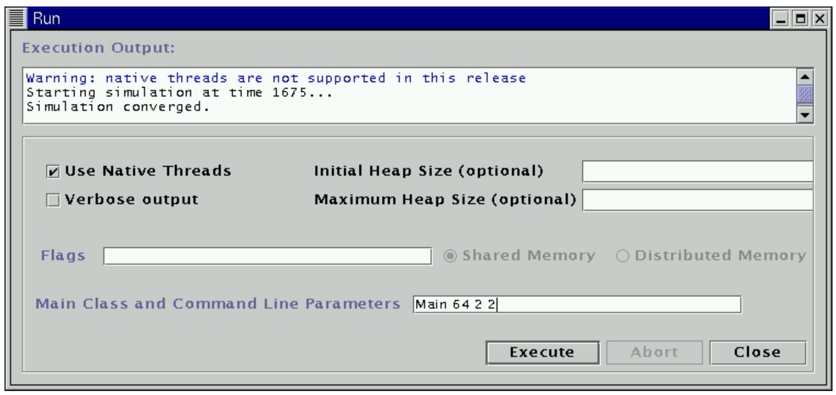


Figure 19: The Run dialog.

eters. The reason for this is that CO_2P_3S may keep source files that were generated based on old values of class names. We currently compile all source files in the `src` directory. However, these old files can interfere with compilation if the code they contain is out of date. This button lets you clean out these old source code files. It is also useful for quickly regenerating code for all of the pattern templates in a program rather than doing it template by template.

Arguments to the compiler can be specified in two ways. Common arguments, for including debugging information (`-g` on the command line), deprecation warnings, optimizations, and verbose output can be indicated with the check boxes. Additional arguments can be inserted into the `Flags` text field. The output of the compiler will appear in the text area at the top of the dialog.

The contents of this dialog are also saved when you save your program, so you won't have to enter this information each time.

4.4.6 Run Dialog

To run your program, select `Run` from the `Program` menu (Figure 17). The Run dialog, shown in Figure 19, will appear.

The Run dialog is much like the Compile dialog. Common options are provided as check boxes or text areas. Other options can be entered into the `Flags` text area. The Run dialog has an

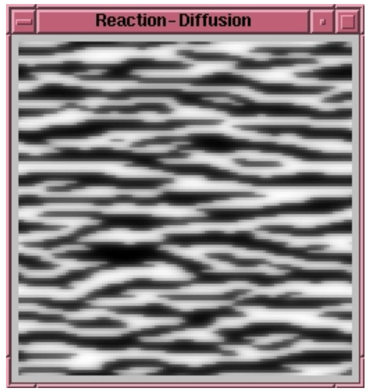


Figure 20: The output of the reaction–diffusion texture generation.

additional text area for specifying the mainline class and command line parameters. The output of the program is displayed in the text area.

The contents of this dialog are also saved when you save your program, so you won't have to enter this information each time.

4.5 Example Programs Supplied with CO_2P_3S

This section briefly describes the example applications that are supplied with this distribution of CO_2P_3S: reaction–diffusion texture generation, parallel sorting by regular sampling, and matrix product chain. These programs can be found in the directory

```
COPSINSTALL/programs
```

More information on these two programs is provided in the `docs` subdirectory for the program.

4.5.1 Reaction–diffusion Texture Generation

The reaction–diffusion texture generation problem is taken from computer graphics [4]. The program simulates two chemical, called *morphogens*, as they simultaneously react with one another and diffuse over a two–dimensional surface. This simulation repeatedly iterates over the surface, computing new values, until the values converge to their final solution. When the simulation is complete, one of the morphogens can be used to render a texture that resembles zebra stripes, as shown in Figure 20.

This texture is generated so that it can be tiled on a larger surface without any noticeable edges between tiles. This is accomplished by allowing the diffusion process to wrap around the edges, both horizontally and vertically, during the simulation.

This program uses the Mesh pattern template. This template parallelizes this computation by spatially decomposing the two–dimensional surface into distinct partitions. These partitions are then assigned to different processors for evaluation. However, the nature of a mesh computation is that each element (or pixel in the texture) requires data from adjacent elements. Thus, each partition needs data from adjacent partitions to compute new values for the elements on its boundary. Further, for each iteration, the new values for the elements are computed using the values from the

previous iteration, which requires barrier synchronization to ensure that no processor computes too far ahead.

The example program executes the simulation (based on a set of command line parameters that are explained in the Program Options Pane of the program). The initial, random conditions are displayed in a window. When complete, the final result is displayed. This window is the only output of the program. You can use image manipulation software to capture this image for later use.

To end the program, you will need to kill this window. Otherwise, the Run dialog will still believe the program is executing.

An interesting note on this program is the reuse of code from the sequential version. All of the classes in the Program Options Pane except the `Main.java` class were taken directly from a sequential implementation of this program. The hook method code is used as an Adapter pattern [1], essentially translating the interface in the generated framework code to the interface required by the reused code. In addition to reusing sequential code, this implementation strategy also keeps the hook method code simple.

4.5.2 Parallel Sorting by Regular Sampling

The second example program implements the Parallel Sorting by Regular Sampling (PSRS) algorithm [2]. This program sorts a specified number of uniformly distributed, random `Integer` objects and verifies the results. This is an explicitly parallel sorting algorithm that does not have a direct sequential counterpart. In addition, this program uses two instances of the Phases and Distributor pattern templates, providing an example of composing multiple frameworks into a complete application.

Composing frameworks in CO_2P_3S is simplified because each framework uses the Facade pattern [1] to provide a single, simple interface to the code. The constructor for this Facade creates all of the objects needed by the framework and assembles them into a complete program, simplifying the instantiation process. The Facade also provides a simple interface for launching the computation for the framework where applicable (seen in the Phases and Mesh frameworks).

4.5.3 Matrix Product Chain

The final example is matrix chain product, one of the Cowichan problems [3]. This program uses a dynamic programming matrix to find the least expensive way to multiply a set of matrices. The program uses a single instance of the Wavefront pattern template, computing the upper half of a matrix starting from the diagonal and working to the top right corner.

4.6 Disabled Interface Options

This version of CO_2P_3S does not have all options enabled. To minimize the number of changes for future versions of CO_2P_3S, most of these options are permanently grayed out in this distribution. These options are:

- The `Create or Edit Pattern` menu item in the `Environment` menu. This is provided for future releases that will provide tools for you to modify or create pattern templates

(Section 5.1).

- The `Tools` menu item on the user interface is disabled. These tools are for managing machines and resources in the forthcoming distributed memory version of CO_2P_3S (Section 5.3).

- The `Shared Memory` and `Distributed Memory` radio buttons in the Run dialog. Shared memory is always selected.

- The `Generate Next Code Layer` in the background menu in the Pattern Pane. This release of CO_2P_3S only supports the Pattern Layer, so this menu item is disabled.

4.7 Caveats

There are a number of issues with the CO_2P_3S user interface. These problems, and potential workarounds where possible, are:

1. You must execute the `runCops` script while your current directory is `COPSINSTALL`. If you run the script from elsewhere, the images in the interface will not be displayed. This will be fixed soon.

2. When editing hook methods in the Viewing Template window, the code for the complete framework is regenerated after each method body is accepted. The time for this generation may be longer than you wish to wait. To prevent this regeneration, uncheck the `Regenerate After Each Change` checkbox. The window will let you know if the code in the window is out of date. Note, though, that the most recent code will be displayed in the Code Editor dialog. It simply won't be shown in the viewer itself. If you recheck this checkbox or close the viewer with out–of–date code, the framework will be regenerated.

3. When you regenerate the complete framework, using either the `Generate First Code Layer` menu item in the Pattern Pane or the `Regenerate All Layer One Source` button on the Compile dialog (but not if you've changed a hook method body), all template viewers and code editors are closed. We cannot check to see if the class in the viewer is still relevant in the application, or if the correct code is being displayed. Closing the viewers and reopening them from the Pattern Pane menu ensures that the viewers always display the most recent version of a class, and that the class is still relevant to the application.

4. Using X11, the graphical user interface may not correctly display over a remote X connection. You will need to run CO_2P_3S on the local machine. As far as we can tell, this is a problem in the Swing library used for the interface.

   This means that you will not be able to use the Run dialog to execute your CO_2P_3S program. Instead, you can run the program manually. In the `classes` directory for your program (Section 4.1) are the class files for your program. You can start the virtual machine using these files, or copy them to other machines as necessary.

5. Using X11, some window managers do not correctly display the user interface, even on the local machine. Once again, this appears to be a problem with Swing. In particular, we have experienced serious problems with the FVWM2 window manager, including the following:

   - The region around the edge of dialog boxes does not render properly, instead appearing as a blank grey region. This may obscure the buttons in the dialog. The buttons are still present and can be clicked, but you will not be able to see what you're clicking. Usually, resizing the dialog will correct this. Another option is to iconify and expand the window, but again this doesn't always work.
   - The size of a dialog window may change each time it is brought up. The dialog may grow slightly each time until it takes up the entire screen. It may shrink slightly until it is too small for all of its components.

   The problems with FVWM2 are apparently known bugs, but fixes do not appear to be forthcoming. The screenshots for this document were all taken using the Enlightenment window manager running under the Gnome desktop on a Linux workstation. We have not experienced any problems with this environment. We cannot vouch for other desktop and window manager combinations.

6. The file list dialog hangs when working on directories with a large number of files. This is why we recommend that you set the userProgramDirectory attribute (Section 2.4.1), either by modifying the `.copsrc.xml` file manually or through the `Edit Preferences` menu item in the user interface.

7. There are a number of exceptions that are thrown by Swing components. Most of the time, these can be safely ignored. Unfortunately, this can make it hard to find the exceptions that are important.

8. Saving a CO_2P_3S program saves the configuration information for an individual program. However, changes within the program are performed immediately, regardless of whether you save the configuration or not. For example, deleting classes or changing hook method bodies take effect immediately and cannot be undone by not saving the program. This also means that it is possible for the configuration and program code to be out of step with one another. We should perhaps follow the emacs approach of creating a working copy and replacing the original when you save the program, but this has not been done.

9. CO_2P_3S requires an open network connection to start. The reason for this is that the format of the `.copsrc.xml` file is verified using a DTD (Document Type Definition) file that is accessed through the World Wide Web. Line 5 of Figure 1 shows the URL of this file. If you will be using CO_2P_3S on a computer without a network connection, you should change this URL to point to the copy of the DTD file included in the CO_2P_3S distribution. Change the URL to the following:

   ```
   file:COPSINSTALL/DTD/CopsCfg.dtd
   ```

   where `COPSINSTALL` is the directory of your CO_2P_3S installation (the value of the copsInstallationDirectory configuration property from Section 2.4.1).

10. When editing code using the Viewing Template, the code for methods that still have their default bodies will not appear in the Code Editor. The proper code is still in the application classes, but simply doesn't appear in the Code Editor dialog. However, you must take care not to accept an empty window by clicking `OK`. This overwrites the default with an empty method body, which will result in compile errors. Either cancel the change or restore the default implementation.

11. There are a number of cases when the displayed HTML and the actual code do not match. The most common example is with the $<$ and $>$ operators. These are not displayed correctly since they are part of HTML tags. The HTML generator does not convert these for proper display. In other cases, we have seen extra newlines inserted into code. These problems only affect the HTML and not the underlying code. The code as it appears in the Code Editor dialog is properly inserted into the source.

12. If no constructors are explicitly added to a class, the code generator will always insert an explicit default constructor that is not editable by the user. This can be a problem for pattern designers, as it means that the user cannot augment the default constructor. (Trying to add the default constructor in user–added code will result in a compile error.) The workaround is to explicitly add the default constructor as part of the generated framework code and make it editable. Another option, which is best for constructors that pass arguments to a parent constructor, is to create a constructor that cannot be edited and that calls an initialize method that the user can implement.

5 Future Enhancements to CO_2P_3S

5.1 MetaCO_2P_3S

One drawback to many pattern–based programming systems is their lack of extensibility. The tool only supports the patterns that the tool developers supply. If a pattern you need for your program is not supported, then you must either abandon the tool, implement the pattern manually, or wait for the system developers to support the pattern.

Future releases of CO_2P_3S will include the MetaCO_2P_3S tool that will allow you to become a *pattern designer*. If the pattern you need doesn't already exist, you can create a pattern template and framework and add it to CO_2P_3S. Similarly, you can correct problems or limitations in existing pattern templates. You can add new parameters to create pattern variations that were not originally supported by the pattern template. You can also modify the framework code to better support applications that the original pattern designer did not consider or to fix bugs.

5.2 Pattern Template Repository

Once we enable pattern designers to create new pattern templates, the next step is to find a means of exchanging them with other CO_2P_3S users. We can envision a Web–based repository for new or modified pattern templates. It should be possible to upload new templates, query the repository for a template that suits your problem, and install that template into your local CO_2P_3S distribution.

Even further, if the format of the meta–templates is system–independent, it is possible for other pattern–based programming systems to take advantage of this repository. Pattern–based tools that can interpret the meta–template format will find they have a large set of supported patterns that can solve a broad range of problems. We believe such a format is possible.

5.3 Distributed Memory Pattern Templates

The current pattern templates in CO_2P_3S are targeted at shared memory multiprocessors. Networks of workstations, clusters, or even grid computing systems are also potential targets for high–performance applications. We are working on versions of our pattern templates that use Java Remote Method Invocation to execute on these kinds of systems. To make it easier for pattern designers to create distributed templates, we are also including JINI as a mechanism for managing remote resources and a library supporting constructs like distribute monitors for synchronization.

Future pattern templates may generate boilerplate code that is required by some grid software libraries, such as Globus. This will make it easier to take advantage of computational grids.

5.4 Support for Sequential Design Patterns

CO_2P_3S was originally envisioned as a pattern–based parallel programming system. It has become clear that these same ideas and programming model are equally applicable to creating programs with sequential design patterns. As we create sequential pattern templates, we will make them available (hopefully using our pattern template repository).

6 Feedback

We would appreciate any feedback that you have on the CO_2P_3S parallel programming system, or reports of any bugs that you find. Please send e–mail to `systems@cs.ualberta.ca`.

References

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